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## Assessment of the microbial load of Nyanchwa-Riana and Nyakomisaro-Riana Rivers, Kisii, Kenya

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### Abstract

Water is an elixir of life, a precious gift of nature to mankind and other animal and plant species living on the planet earth. Water quality was assessed in two parallel rivers flowing through Kisii town. Parameters assessed were; Electrical Conductivity, TDS, TSS, pH, temperature, total and fecal coliform counts monthly for 18 months along five sampling sites in the rivers' transects. Mean TDS in Nyanchwa and Nyakomisaro rivers were  $142.59 \pm 22.68 \text{ mgL}^{-1}$  and  $96.62 \pm 11.76 \text{ mgL}^{-1}$  respectively. Nyanchwa had an overall EC of  $110.35 \pm 2.09 \text{ } \mu\text{Scm}^{-1}$  while Nyakomisaro had  $107.55 \pm 4.15 \text{ } \mu\text{Scm}^{-1}$ . EC was also correlated with TDS, temperature, TSS, T-coli and F-Coli at all sites. TSS in Nyanchwa River and Nyakomisaro ranged from  $2.00 - 396 \text{ mgL}^{-1}$  with an overall mean of  $53.86 \pm 5.67 \text{ mgL}^{-1}$  and  $56.38 \pm 6.45 \text{ mgL}^{-1}$  respectively. TSS had significant differences in sampling sites and was above the recommended NEMA levels of  $30 \text{ mgL}^{-1}$ . F-Coli was strongly correlated with the T-Coli in the two rivers. Nyanchwa had an overall mean of fecal and total coliforms of  $740 \pm 94 \text{ cells}100\text{ml}^{-1}$  and  $627 \pm 112 \text{ cells}100\text{ml}^{-1}$  respectively while Nyakomisaro had an overall mean of fecal coliform counts of  $786 \pm 104 \text{ cells}100\text{ml}^{-1}$  and mean total coliform counts were  $842 \pm 105 \text{ cells}100\text{ml}^{-1}$ . Chlorophyll-a in both rivers was not significantly different across the sampling sites. Both rivers had chlorophyll-a concentrations beyond  $10 \mu\text{gL}^{-1}$ . The results suggested that environmental loading of pollutants from car washing sites, leaked sewage, defecation in the bushes, organic wastes and dumping soils from construction sites adversely altered natural stream water quality dynamics, underlining the need for improved management practices, including controlling leachate from dumpsites into the rivers to minimize the large-scale escape of pollutants into the rivers.

**Keywords:** Nyakomisaro-Riana, Nyanchwa-Riana, microbial load; TDS; conductivity; water quality

### 1. Introduction

Water is regarded as an elixir of life, a precious gift of nature to mankind and other millions of species living on the planet earth. Water resources comprising of surface water (river and lakes), ground water, and marine and coastal waters support all living things including human beings. Though available in huge quantities in the order of  $1400 \times 10^6 \text{ km}^3$ , only less than 3% is reliable and accessible. Globally, 505,000 cubic kilometers of renewable fresh water shifts from the sea to land every year as rain or snow via the hydrological cycle; but only 47,000 cubic kilometers per year is considered accessible for human use<sup>[1, 2]</sup>. This meager percentage is under pressure from anthropogenic pollutants, making fresh water the most critical resource issue facing humanity. While the supply of fresh water is limited, both the world's population and demand for fresh water resource continues to expand rapidly. Water as a resource is fast becoming a scarce and costly commodity in most parts of the world than ever imagined<sup>[3]</sup>.

Intensive human and animal sewage leakage is associated with numerous environmental and human health effects<sup>[4, 5]</sup>, but nitrogen, phosphorus, and microbial escape into water are of particular concern<sup>[6]</sup>. Significant threats to water quality is attributed to proximity of surface water to lagoons<sup>[7, 8]</sup> and may be further aggravated by spills, leakage from constructed pit latrines near waterbodies and illegal dumping of solid wastes directly or into dumpsites near waterbodies. Precipitation, erosion, and flooding exacerbate contaminant escape from these sites into rivers<sup>[9]</sup>. Location of human structures and livestock facilities beside streams and watering them in the waterbodies make water to be most vulnerable to contamination from pathogenic microbes found in their excreta<sup>[10]</sup>.

Safe water is that which is free from pathogenic microorganisms, radioactivity, chemical contamination, or turbidity and should not possess undesirable taste, odor, or color<sup>[11]</sup>. Total

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coliform bacteria (T-Coli) are a collection of relatively harmless microorganisms residing in the gut of both cold and warm blooded organisms. Part of this collection is fecal coliform bacteria. Fecal coliform bacteria (F-Coli) can only be associated with the fecal matter of warm blooded animals and grow at elevated temperatures. It may occur in ambient water coming from point domestic sewage or nonpoint sources of pollution. Pathogenic microbes are found in fecal material alongside coliform bacteria. The occurrence of fecal coliform in aquatic environments signifies water contamination via the fecal matter from wild, domestic or human excreta. Hence, their presence in rivers and streams suggest a potential health risk for individuals utilizing such water<sup>[11]</sup>.

Onwumere (2006)<sup>[12]</sup> found that storm water runoff is a conduit through which various types of pollutants like septic tank discharges, animal wastes, fertilizers from agricultural fields and other pollutants like grease, metals and oils generated from car washing sites and garages find their way into waterbodies. Marcotullio (2006)<sup>[13]</sup> also identified discharging of untreated solid and liquid waste, increasing silt loads due to urban land use expansion, leakages of wastewater treatment plants as the major causes of urban river pollution. Heavy rain conditions can result in high fecal coliform counts downstream from sewage discharge points. Gautam (2006)<sup>[14]</sup> showed that the high coliform count in waterbodies was related to rain events, and the major sources of fecal coliform contamination are the runoffs from urban areas.

Globally, most waterbodies are recipients of the industrial and municipal wastes which utilize dissolved oxygen in these waters<sup>[15]</sup>. Oxygen demanding wastes such as sewage are more serious pollutants in natural environment due to their health effect. Water polluted by sewage or effluents from sewage treatment plants is associated with heavy disease burden<sup>[16]</sup>. Introduction of elevated levels of sewage into

recipient water bodies contribute to increased algal blooms due to nutrient loading of water bodies which in turn leads to increased oxygen demand.

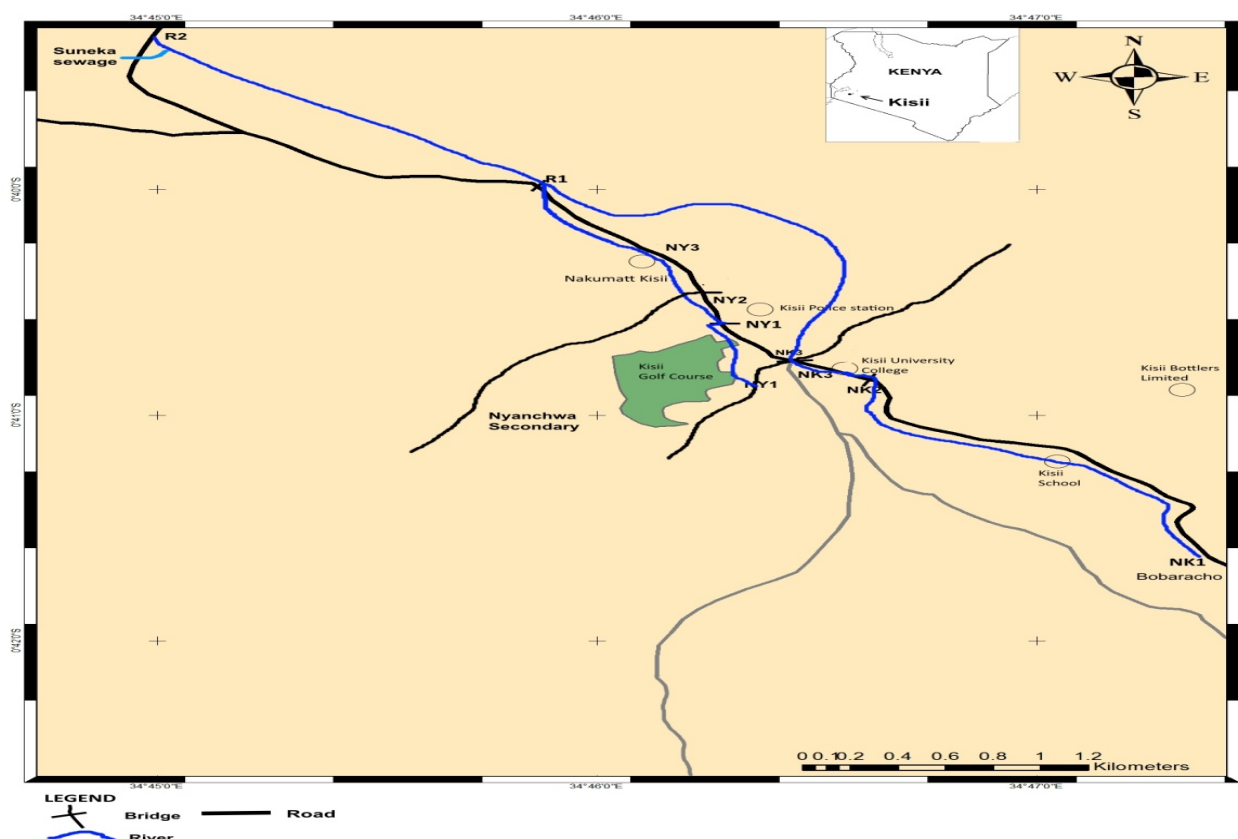
Wastewater from industries and sewage from homes and offices are released directly into streams and rivers. Most waste treatment methods are substandard since they partially treat and in some instances, forego the effluent treatment process<sup>[17]</sup>. Indiscriminate discharges of industrial and municipal wastes into rivers need monitoring to protect human health and aquatic species. Puyate, *et al.*, (2007)<sup>[17]</sup> posited that scarcity of clean water and pollution of freshwater/ has led to a situation where one-fifth of urban dwellers in developing countries and three quarters of rural dwelling population lack access to safe water supplies.

Therefore, this research was mainly focused to assess the water quality of two parallel streams flowing through Kisii town in South Western Kenya which are important sources of water to most inhabitants of Kisii town. Levels of Total suspended solids (TSS), Total dissolved solids (TDS), Electrical conductivity (EC), Fecal coliform counts (F-Coli), Total coliform counts (T-Coli), Chlorophyll a, Alkalinity, temperature and dissolved oxygen (DO) were assessed.

## 2. Materials and Methods

### 2.1 Study area and Sampling sites

The study area constituted two streams – Nyanchwa and Nyakomisaro and one river – Riana flowing through Kisii Town. The town is located at an altitude of 1850 meters above sea level and stretches from longitude 34°45'0"E to 34°47'0"E and latitude 0°40'0"S to 0°42'0"S in South Western Kenya. It is situated approximately 300 km South West of Nairobi on the highway to Mwanza, Tanzania. It has a highland equatorial climate, with an average rainfall of 2000 mm yr<sup>-1</sup>.



**Fig 1:** Map showing the location of the study area and its sampling sites. (NK1 & NY1: upstream, NK2 & NY2: midstream, NK3 & NY3: downstream R1 and R2 after the two streams have confluenced at Daraja Mbili)

Three (3) sampling sites in both Nyanchwa stream (NY1, NY2 and NY3) and Nyakomisaro stream (NK1, NK2 and NK3) were marked and after their confluence at Daraja Mbili market to form Riana River, two more sites (R1 and R2) were established along the length of the studied part of the Nyanchwa –Riana and Nyakomisaro – Riana River profiles. Surface water samples were collected from sampling sites. Sampling was carried out monthly for 18 months between May 2013 and October 2014.

## 2.2 Sampling procedures for *in situ* parameters

Sampling procedures followed the standardized protocols elaborated in APHA 1998 [18]. Three measurements of the selected physico-chemical parameters were done *in situ* at each sampling site using respective meters: Dissolved oxygen concentration ( $\text{mg l}^{-1}$ ) and temperature ( $^{\circ}\text{C}$ ) were measured using an oxygen meter model YSI 15B; pH was measured using a Digital Mini Model 49- pH meter and Electrical conductivity ( $\mu\text{Scm}^{-1}$ ) was measured using an electrical conductivity meter model LF 96. All the meters used had a measurement accuracy of  $\pm 0.01$ .

For laboratory analyses, water samples for fecal coliform counts were collected in sterilized bottles. All containers were pre-cleansed by washing with non-ionic detergents, rinsed with tap water, 1:1 hydrochloric acid and finally with de-ionized water. The sampling bottles were then labeled according to the sampling sites. Prior to sampling, the bottles were rinsed three times with sample water before being filled with the sample (in order to acclimatize with the sample water environment). Sampling was carried out by dipping each sample bottle at approximately 10- 20cm below the water surface by projecting the mouth of the container against the flow the direction. Preservatives were added in the specific test methods in order to avoid changes in chemical composition of samples as a result of microbial and algae degradation and inter-chemical reaction. Samples were then transported in cooler boxes containing ice blocks at  $4^{\circ}\text{C}$  to Kenya Marine and Fisheries Research Institute Laboratory, Kisumu for analyses within a period of 24 hours after collection.

## 2.3 Laboratory Measured Parameters

### 2.3.1 Total Suspended Solids

A defined volume of water samples was filtered using pre-weighed filters and dried at  $95\pm 5^{\circ}\text{C}$  for 3 hours until a constant weight was achieved. The concentration of total suspended solids was then estimated gravimetrically on glass-fibre filters Whatman GFC, after drying to constant weight at  $95^{\circ}\text{C}$ . The weight of suspended solids was computed using the formulae below:

$$\text{TSS (mg l}^{-1}\text{)} = ((\text{Wc}-\text{Wf}) \times 10^6) / \text{V}$$

Where TSS = Total suspended solids,

Wf = Weight of pre-combusted filter in grams;

Wc = Constant weight of filter + residue in grams;

V = Volume of water sample used in ml

Total dissolved solid (TDS) were estimated from conductivity measurements by multiplying with a factor of 0.6 as follows:

$$\text{TDS (mg/L)} = \text{EC } (\mu\text{S/cm at } 25^{\circ}\text{C}) \times 0.6$$

### 2.3.2 Chlorophyll-a Determination

One Sample was collected from each site for the measurement of chlorophyll-a concentration. The samples were then filtered

through a 7cm diameter Whatman GFC filter paper of pore size  $0.45\mu$  using a hand vacuum filter pump. The filter paper was then inserted in a 25 ml test tube containing 15 ml of ethanol. The test tube was further rubbed in aluminum foil and put in an ice cooler box overnight to allow the extraction of chlorophyll-a into the ethanol solution. After this, the filter paper was squeezed to remove the remaining chlorophyll-a into the test tube. 11 milliliter of the chlorophyll-a in the test tube was put in centrifuge cuvettes and centrifuged at 2500 rpm for 10 minutes. The supernatant chlorophyll-a solution was decanted into 1cm pathway spectrophotometer cuvette and absorbance measurements carried out at wavelengths of 750 nm and 665 nm. The absorbance of chlorophyll-a concentration was obtained by subtracting the two absorbencies respectively. The chlorophyll-a concentration was calculated using the Talling & Driver (1961) [19] formulae as follows;

$$\text{Chl-a, } \mu\text{g l}^{-1} = [11.40 (\text{E665} - \text{E750}) * \text{V}_1] / (\text{V}_2 * \text{L})$$

Where: 11.40 is the absorption coefficient for chl-a,

$\text{V}_1$  = volume of extract in ml;

$\text{V}_2$  = volume of the filtered water sample in litres;

L = light path length of cuvette in cm;

E665, E750 = optical densities of the sample.

### 2.3.3 Micro-Biological Analyses (Total and Faecal coliform counts)

Using Hamper bottles, water samples were collected and kept in ice for further analysis. Multitube technique was used to determine coliform pathogens. 100ml of sample was passed through a filtration unit. The filtrate was placed on petri-dishes containing endo broth media on a filter pad for resuscitation of microbes thereafter placed in an incubator for 18 – 24 hours, at  $37^{\circ}\text{C}$ . The samples were removed and metallic sheen colonies counted and recorded as *Escherichia coli*. The Oxoid media brilliant green bile agar was prepared a day prior to sampling and left to gel at  $4^{\circ}\text{C}$ . 0.1 ml inoculum was pipetted and poured on the media in a petri-dish and aseptically spread all over the media and incubated at  $37^{\circ}\text{C}$  for between 18 – 24 hours. After incubation period, tiny and colourless colonies were counted and results recorded as colony forming units (CFU). For confirmation, gram stain was performed and results interpreted.

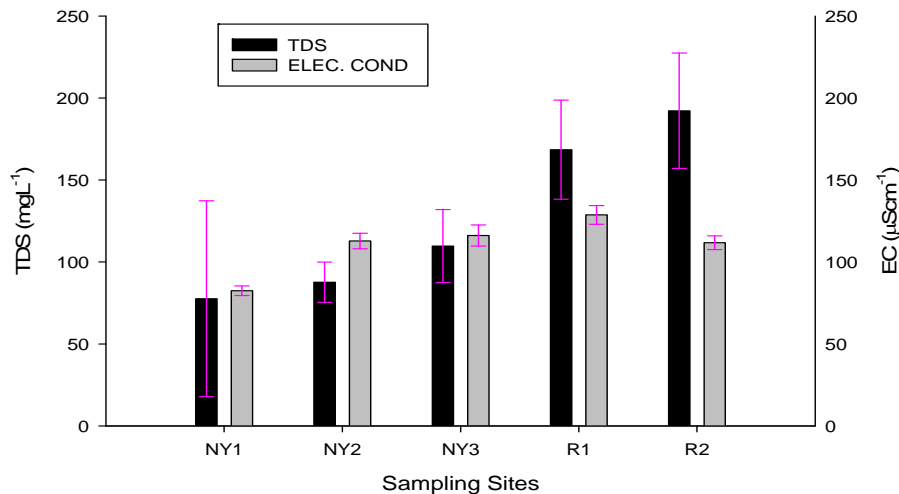
## 3. Results

### 3.1 Total Dissolved Solids and Electrical Conductivity in Nyanchwa-Riana River

The measured Total Dissolved Solids (TDS) were not different along the sampling sites of Nyanchwa-Riana River (figure 2). Sampling site NY1 had the lowest average TDS of ( $77.52\pm 59.70 \text{ mgL}^{-1}$ ) while site R2 had the highest TDS ( $192.18\pm 35.21 \text{ mgL}^{-1}$ ). The overall mean TDS along the river was  $142.59\pm 22.68 \text{ mgL}^{-1}$  with a range of 2.00 –  $1420.00 \text{ mgL}^{-1}$  (table 1). Electrical conductivity (EC) was lowest at sampling site NY1 ( $82.48\pm 2.94 \mu\text{Scm}^{-1}$ ) while site R1 had the highest EC ( $128.69\pm 5.69 \mu\text{Scm}^{-1}$ ) (figure 2). The overall mean EC along the Nyanchwa-Riana River was  $110.35\pm 2.09 \mu\text{Scm}^{-1}$  with a range of 53.70 –  $257.00 \mu\text{Scm}^{-1}$  (table 1).

**Table 1:** The Physic-chemical parameters of the Nyanchwa –Riana River during the May 2013 – October 2014 sampling period

Parameter	Size (n)	Range	Mean	STDEV	SE	95% CI
pH	270	5.12 – 9.00	6.97	0.53	0.07	0.14
Temperature (°C)	270	18.90 – 24.00	21.21	1.00	0.16	0.32
Conductivity ( $\mu\text{Scm}^{-1}$ )	270	53.70 – 257.00	110.35	15.35	2.09	4.19
Dissolved Oxygen (DO) ( $\text{mg L}^{-1}$ )	270	3.29 – 9.07	6.01	0.61	0.08	0.17
Total Suspended Solids ( $\text{mg L}^{-1}$ )	270	2.0 – 396.0	53.86	41.68	5.67	11.38
Total Dissolved Solids ( $\text{mg L}^{-1}$ )	270	2.00 – 1420.00	142.59	141.63	22.68	45.91

**Fig 2:** Mean TDS and EC along the Nyanchwa – Riana River during May 2013 to October 2014 sampling period.

The ANOVA of TDS along the Nyanchwa-Riana River did not indicate any significant difference along this river's transect ( $F_{4, 269} = 0.87$ ;  $P = 0.483$ ). The noted anthropogenic activities along the five sampling points of Nyanchwa – Riana River, indicate that they were releasing lots of TDS into the Nyanchwa-Riana River hence not giving it good time to clean itself before the next sampling point (figure 2). The solid wastes and dumped soils from construction sites of Nyanchwa catchment included raw sewage, oils from garages, soap froth from car washes and various dissolved ions from dumped soils hence increasing the river's EC along its' transect.

Electrical conductivity's ANOVA did indicate a significant difference along the Nyanchwa-Riana River transect ( $F_{4, 269} = 11.79$ ;  $P = 0.000$ ). Sampling sites' comparison by the Tukey's Pairwise comparison method indicated that EC at NY1 was significantly different from all the lower sampling sites. Site NY1 was significantly lower by between 11.18 – 49.36  $\mu\text{Scm}^{-1}$  than site NY2, 14.51- 52.70  $\mu\text{Scm}^{-1}$  than site NY3, 27.11 – 65.30  $\mu\text{Scm}^{-1}$  than R1 and 10.18 -48.37  $\mu\text{Scm}^{-1}$  than sampling R2. Sampling site NY2 was not significantly different from

sites NY3, R1 and R2. Electrical Conductivity at sampling site NY3 was not significantly different from that of sites R1 and R2 and comparably site R1 showed no significant difference from sampling site R2. These EC differences might be attributed to the various anthropogenic activities going on along the Nyanchwa-Riana River. For example at NY3 whose range was between 27.11 – 65.30  $\mu\text{Scm}^{-1}$  can be attributed to the heavy washing of cars near this point and the oils from garages near NY3 sampling point which were releasing lots of oils into the river.

### 3.2 Total Dissolved Solids and Electrical Conductivity in Nyakomisaro – Riana River

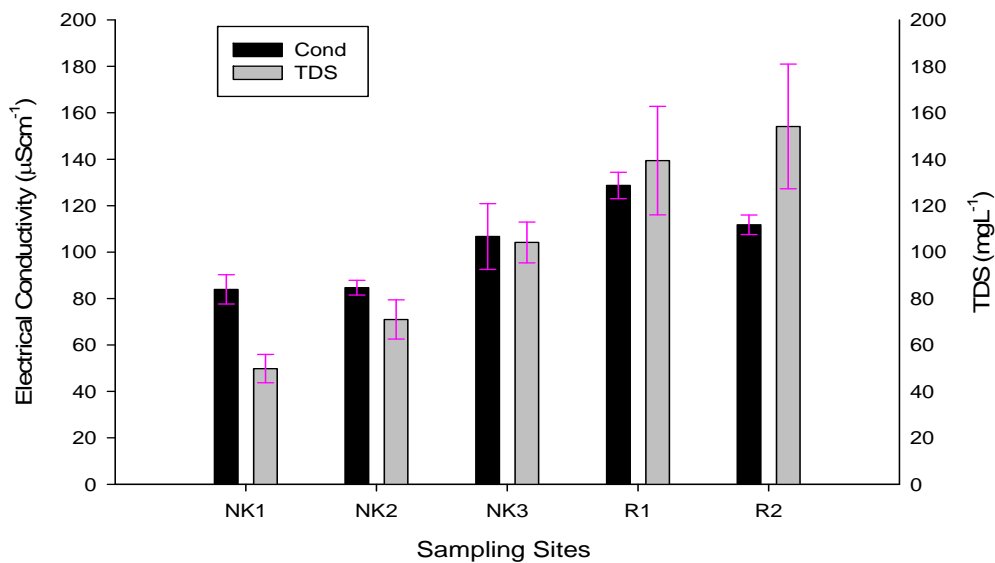
The TDS measured showed a spatial difference along the five sampling sites of Nyakomisaro-Riana River (figure 3). The overall mean TDS was  $96.62 \pm 11.76 \text{ mgL}^{-1}$  with a range of 2.00 – 781.00  $\text{mgL}^{-1}$  (table 2). Sampling site NK1 had the lowest average TDS of  $49.8 \pm 6.12 \text{ mgL}^{-1}$  while site R2 had the highest TDS of  $154.1 \pm 26.86 \text{ mgL}^{-1}$  (figure 3).

**Table 2:** The Physic-chemical parameters of the Nyakomisaro –Riana River during the May 2013 – October 2014 sampling period

Parameter	Size (n)	Range	Mean	STDEV	SE	95% CI
pH	270	5.12 – 9.00	7.08	0.43	0.06	0.12
Temperature (°C)	270	17.60 – 27.80	21.32	1.92	0.26	0.52
Conductivity ( $\mu\text{S cm}^{-1}$ )	270	31.40 – 509.00	107.55	30.52	4.15	8.33
Dissolved Oxygen (DO) ( $\text{mg L}^{-1}$ )	270	3.29 – 9.79	6.24	0.65	0.09	0.18
Total Suspended Solids ( $\text{mg L}^{-1}$ )	270	2.00 – 396.00	56.38	47.36	6.45	12.93
Total Dissolved Solids ( $\text{mg L}^{-1}$ )	270	2.00 – 781.00	96.62	86.44	11.76	23.59

The mean EC of Nyakomisaro-Riana River showed a similar difference with TDS in the five sampling sites. The overall EC mean was  $107.55 \pm 4.15 \mu\text{Scm}^{-1}$  with a range of 31.40 – 509.00

$\mu\text{Scm}^{-1}$  (table 2). Sampling site NK1 had the lowest EC of  $83.94 \pm 6.31 \mu\text{Scm}^{-1}$  and site R1 had the highest EC of  $128.69 \pm 5.69 \mu\text{Scm}^{-1}$  (figure 3).



**Fig 3:** Mean TDS and EC along Nyakomisaro – Riana River during the May 2013 to October 2014 sampling period.

The Pearson’s correlation was performed and did indicate that EC was positively correlated with the TDS ( $r = 0.89, p = 0.044$ ), Temperature ( $r = 0.90, p = 0.037$ ) and TSS ( $r = 0.975, p = 0.005$ ) (table 3). The sampling site differences in TDS and EC along this river can be attributed to the agricultural

activities along the Nyakomisaro – Riana River, froth from the washing of clothes and cars in this river, sewage leakage and organic waste which are often dumped into this river from the town and the surrounding community.

**Table 3:** Pearson Correlation Coefficient(*r*) and *p*-values for EC, TDS, TEMP, SALINITY, TSS, Ph, T-coli, F-Coli parameter relationships of Nyakomisaro-Riana River for the 18-months sampling period

	EC	TDS	TEMP	SALINITY	TSS	pH	T-Coli	F-Coli
<b>TDS</b>	0.889 0.044*							
<b>TEMP</b>	0.901 0.037*	0.989 0.001*						
<b>SALINITY</b>	0.843 0.073	0.926 0.024*	0.938 0.018*					
<b>TSS</b>	0.975 0.005*	0.898 0.038*	0.936 0.019*	0.888 0.044*				
<b>pH</b>	-0.796 0.107	-0.461 0.435	-0.534 0.354	-0.358 0.372	-0.798 0.106			
<b>T-Coli</b>	0.949 0.014*	0.870 0.055	0.847 0.07	0.716 0.174	0.875 0.052	-0.652 0.233		
<b>F-Coli</b>	0.948 0.014*	0.852 0.067	0.832 0.080	0.695 0.193	0.874 0.053	0.676 0.211	0.999 0.000*	
<b>CHL a</b>	0.844 0.072	0.956 0.011*	0.979 0.004*	0.863 0.060	0.900 0.037*	0.490 0.402	0.807 0.099	-0.795 0.108

(Upper numbers represent Pearson's *r*, and lower numbers represent *p*-values; \* shows significant relationship)

An analysis of variance was done using Minitab software and did indicate that TDS were significantly different among the sampling sites of the Nyakomisaro-Riana River transect ( $F_{4, 269} = 7.53; p = 0.000$ ). Tukey’s Pairwise comparison indicated that TDS at NK1 were not significantly different from the TDS at sampling sites NK2 and NK3 but were significantly lower by between 23.8 - 155.4  $\text{mgL}^{-1}$  and 38.5 – 170.1  $\text{mgL}^{-1}$  than those at sampling sites R1 and R2 respectively. The TDS at sampling site NK2 were not significantly different from site NK3 but were significantly lower by between 2.6 - 134.2  $\text{mgL}^{-1}$  and 17.3 – 149.0  $\text{mgL}^{-1}$  than the TDS of sites R1 and R2 respectively. TDS at NK3 were significantly less by between 4.7 - 136.4  $\text{mgL}^{-1}$  and 19.4 – 151.1  $\text{mgL}^{-1}$  than those of R1 and R2 respectively, and TDS at site R1 were not of any

significant difference from those of site R2. The TDS in all these sampling sites were significantly different with 95% confidence interval.

ANOVA results indicated that EC was significantly different along Nyakomisaro-Riana River transect ( $F_{4, 269} = 8.31; p = 0.000$ ). Tukey’s Pairwise comparison indicated that EC at NK1 was not significantly different from those at NK2 and R2 but was significantly lower by between 14.88 – 74.65  $\mu\text{Scm}^{-1}$  and 14.87 – 74.64  $\mu\text{Scm}^{-1}$  than those at NK3 and R1 respectively. Electrical conductivity at site NK2 was significantly lower by between 14.13 – 73.91  $\mu\text{Scm}^{-1}$  and 14.12 – 73.89  $\mu\text{Scm}^{-1}$  than those at sites NK3 and R1 respectively but not significantly different from the EC at sampling site R2. Electrical conductivity at sampling site NK3

was not significantly different ( $p \leq 0.05$ ) from those at sites R1 and R2 and site R1 had no difference in EC with that at site R2. All these pairwise comparisons among levels of sampling sites had a 95% simultaneous confidence interval. The EC differences at NK3 and R1 can be attributed to the heavy car washing at Daraja Moja, Nyambara dumpsite leachate and occasional sewage leakage few meters before sampling site R3.

**3.3 Total Suspended Solids along Nyanchwa-Riana River**

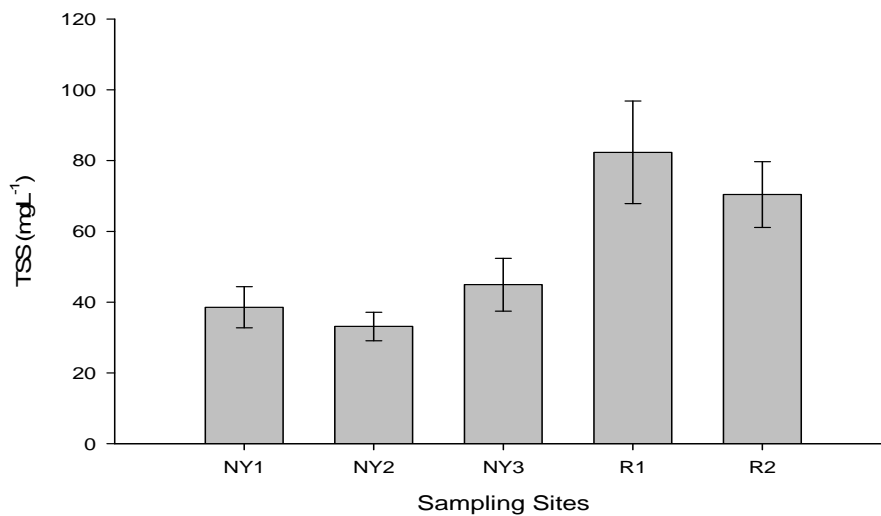
Sampling site NY2 of Nyanchwa-Riana River had the lowest mean TSS ( $33.12 \pm 4.02 \text{ mgL}^{-1}$ ) while R1 had the highest mean TSS of  $82.31 \pm 14.48 \text{ mgL}^{-1}$  (figure 4). The TSS range was between  $2.00 - 396.00 \text{ mgL}^{-1}$  and the overall mean TSS along this river was  $53.86 \pm 5.67 \text{ mgL}^{-1}$  (table 1). The TSS in Nyanchwa-Riana River had a positive correlation with TDS ( $r = 0.92$ ;  $p = 0.027$ ), T-Coli =  $0.928$ ;  $p = 0.023$ ) and F-Coli.

**Table 4:** Pearson Correlation Coefficient( $r$ ) and  $p$ -values for EC, pH,

TSS, TDS, TEMP, T-COLI and F-COLI parameter relationship of Nyanchwa-Riana River for the 18-months sampling period

	EC	pH	TSS	TDS	TEMP	T-Coli
<b>pH</b>	-0.493					
	0.399					
<b>TSS</b>	0.600	-0.204				
	0.285	0.742				
<b>TDS</b>	0.592	0.122	0.920			
	0.293	0.846	0.027*			
<b>TEMP</b>	0.424	0.057	0.622	0.640		
	0.477	0.928	0.263	0.245		
<b>T-Coli</b>	0.806	-0.304	0.928	0.875	0.753	
	0.099	0.619	0.023*	0.052	0.142	
<b>F-Coli</b>	0.736	-0.097	0.940	0.957	0.756	0.975
	0.156	0.877	0.017*	0.011*	0.139	0.005*

(Upper numbers represent  $r$ , and lower numbers represent  $p$ -values. \* shows significant relationship)

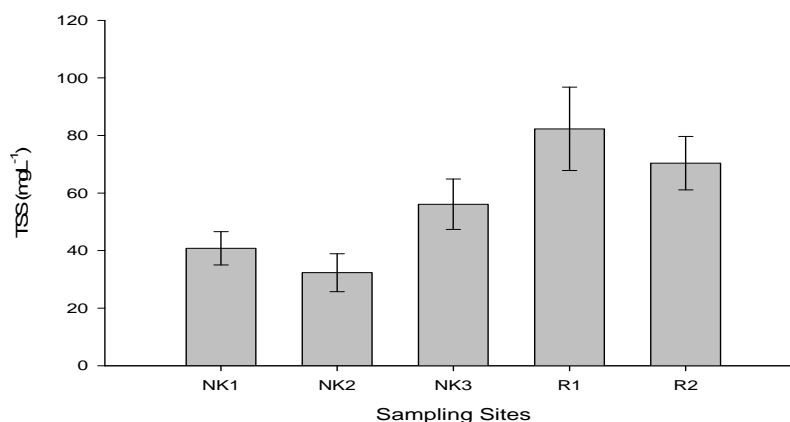


**Fig 4:** Mean Total Suspended Solids along the Nyanchwa – Riana River during the May 2013 to October 2014 sampling period.

**3.4 Total Suspended Solids along the Nyakomisaro -Riana River**

The TSS from Nyakomisaro-Riana River ranged from  $2.00 - 396.00 \text{ mgL}^{-1}$  with overall mean TSS of  $56.38 \text{ mgL}^{-1}$  (table 2). Sampling site NK2 had the lowest average TSS of  $32.8 \pm 6.59 \text{ mgL}^{-1}$  while R1 had the highest mean TSS of  $82.31 \pm 14.48$

$\text{mgL}^{-1}$  (figure 5). The difference in TSS along this river was attributed to dumping of excavated soils from construction sites along the river, eroded silt due to farming along the riparian zones of this river, sewage leakage and organic waste dumped into the river.



**Fig 5:** Mean Total Suspended Solids along the Nyakomisaro – Riana River during the May 2013 to October 2014 sampling period

Total suspended solids were compared according to sampling sites through Pairwise comparison and indicated significant differences ( $F_{4, 269} = 4.70$ ;  $p = 0.001$ ). TSS at Sampling site NK1 were not significantly different from those of sampling

site NK2, NK3 and R2 but were significantly lower by between  $5.29 - 78.48 \text{ mgL}^{-1}$  than those of sampling site R1. Site NK2 was significantly lower by between  $13.11 - 86.3 \text{ mgL}^{-1}$  than those of R1 and between  $1.19 - 74.38 \text{ mgL}^{-1}$  than

those of R2 but was not significantly different from those at site NK3. TSS of sampling site NK3 compared with those of other lower sites (R1 and R2) showed no significant difference. Total suspended solids at site R1 were not significantly different from those at sampling site R2. The TSS range differences were with 95% confidence interval.

### 3.5 Fecal and Total coliform counts in Nyanchwa –Riana River

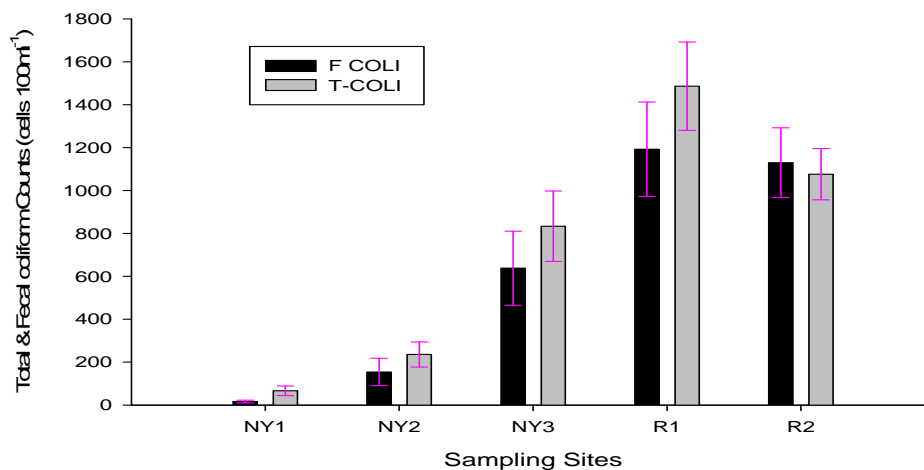
The Total coliform counts (T-Coli) for Nyanchwa-Riana River generally showed a monotonic increase and a positive correlation with fecal coliform counts ( $r= 0.975$ ;  $p = 0.005$ ). Sampling site NY1 had the lowest average fecal coliform counts of  $16.15\pm 6.11$  cells $100\text{ml}^{-1}$  while site R1 had the highest F-Coli  $1992.31\pm 220.30$  cells $100\text{ml}^{-1}$  (figure 6).

**Table 5:** The Chl a, T-Coli and F-coli in the Nyanchwa -Riana River during the May 2013 - October 2014 Sampling period.

Parameter	Size (n)	Range	Mean	STDEV	SE	95% CI
Chlorophyll-a ( $\text{mg L}^{-1}$ )	270	0.00 - 4839.00	242.66	440.66	59.97	165.19
Total Coliform counts ( $\text{Cells } 100\text{ml}^{-1}$ )	270	0.00 - 4300.00	739.71	684.95	93.21	186.96
Fecal coliform counts ( $\text{Cells } 100\text{ml}^{-1}$ )	270	0.00 - 4100.00	626.08	694.44	111.20	225.11

The Total coliform counts were higher than fecal coliform counts in all the sampled stations and showed similar increment trends to those of the F-coli. Sampling site NY1 had the lowest total coliform counts of  $67\pm 25$  cells $100\text{ml}^{-1}$  and site

R1 had the highest T-coli of  $1487\pm 206$  cells $100\text{ml}^{-1}$  (figure 6). The mean total and fecal coliform counts were  $740\pm 94$  cells $100\text{ml}^{-1}$  and  $627\pm 112$  cells $100\text{ml}^{-1}$  respectively (table 6).



**Fig 6:** Fecal coliform counts along the Nyanchwa – Riana River during the May 2013 to October 2014 sampling period

There were very high significant differences in fecal coliform counts between the five sampling sites of Nyanchwa – Riana River ( $F_{4, 269} = 17.88$ ;  $P = 0.000$ ). Fecal coliform counts in sampling site NY1 were not significantly different from those of sampling site NY2 but were significantly lesser by between 241 – 1275 cells $100\text{ml}^{-1}$  than NY3, between 872 – 1906 cells $100\text{ml}^{-1}$  than R1 and between 433 – 1467 cells $100\text{ml}^{-1}$  than R2. Site NY2 had significantly lower fecal coliform counts by between 53 – 1087 cells $100\text{ml}^{-1}$  than that of NY3, between 684 – 1718 cells $100\text{ml}^{-1}$  than that of R1 and not significantly different from those at R2. Sampling site NY3 compared with other lower sites (R1 and R2) showed no difference in fecal coliform counts and site R1 was not significantly different from that of site R2. All these fecal coliform counts difference were with a 95% Confidence Interval.

Total coliform counts (T-Coli) showed similar trends of very high significant differences in the five sampling sites of Nyanchwa-Riana river ( $F_{4, 269} = 25.35$ ;  $p = 0.000$ ). Total coliform counts in sampling site NY1 were not significantly different from those of sampling site NY2 but were significantly lesser by between 339 – 1482 cells $100\text{ml}^{-1}$  than NY3, between 1128 – 2271 cells $100\text{ml}^{-1}$  than R1 and between 963 – 2106 cells $100\text{ml}^{-1}$  than those at site R2. Sampling site NY2 but were significantly lesser by between 49 – 1191

cells $100\text{ml}^{-1}$  than NY3, between 837 – 1980 cells $100\text{ml}^{-1}$  than R1 and between 672 – 1815 cells $100\text{ml}^{-1}$  than R2. Sampling site NY3 was significantly lower by 217 – 1360 than site R1 and 52 – 1195 than R2 and T-Coli at site R1 were not significantly different from those of site R2. All these total coliform counts differences were with a 95% Simultaneous Confidence Interval.

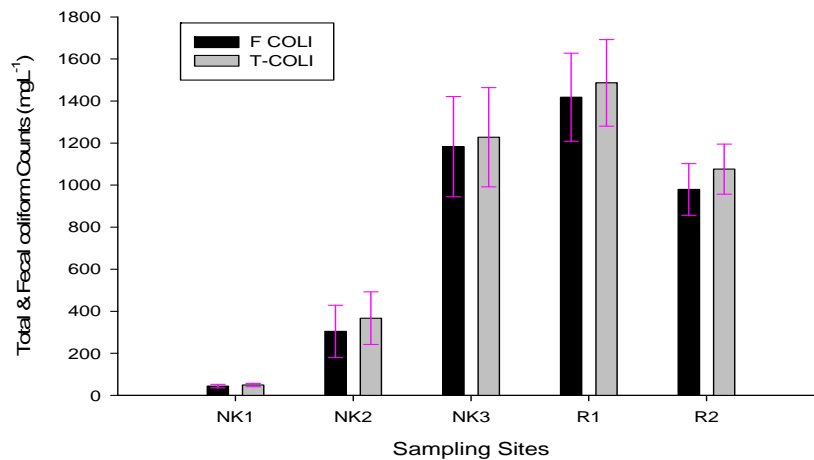
### 3.6 Fecal coliform counts in Nyakomisaro –Riana River

Sampling site NK1 had the lowest average fecal coliform counts of  $43.8\pm 8.18$  cells $100\text{ml}^{-1}$  while site R1 had the highest F-Coli and T-coli of  $1419\pm 210$  cells $100\text{ml}^{-1}$  and  $1487\pm 206$  cells $100\text{ml}^{-1}$  respectively. Generally, there was a monotonic increase of total and fecal coliform counts down the river (figure 7). The range of both Fecal and Total coliform counts were 0 - 4500 cells $100\text{ml}^{-1}$  and the mean Fecal coliform counts was  $786\pm 104$  cells $100\text{ml}^{-1}$  and mean total coliform counts was  $842\pm 105$  cells $100\text{ml}^{-1}$  (table 6).

The high fecal coliform counts at R1 were attributed to sewage leakage which spills into the river, animals which are watered at various points of this river and the toilet spill over which are along the riparian zones of river. At sampling site R2, the high fecal coliform counts can be attributed to the Suneka Lagoon sewage release into the Riana River which is not well treated to lessen the fecal coliform counts.

**Table 6:** The Chl a, T-Coli and F-coli in the Nyakomisaro -Riana River during the May 2013 - October 2014 Sampling period.

Parameter	Size (n)	Range	Mean	STDEV	SE	95% CL
Chlorophyll-a ( $\mu\text{g L}^{-1}$ )	270	0.00 - 4839.00	257.13	359.20	48.88	98.04
Total Coliform counts (Cells 100ml <sup>-1</sup> )	270	0.00 - 4500.00	841.34	766.72	104.34	209.27
Fecal coliform counts (Cells 100ml <sup>-1</sup> )	270	0.00 - 4500.00	785.83	757.80	103.12	206.84

**Fig 7:** Fecal coliform counts along the Nyakomisaro – Riana River during the May 2013 to October 2014 sampling period.

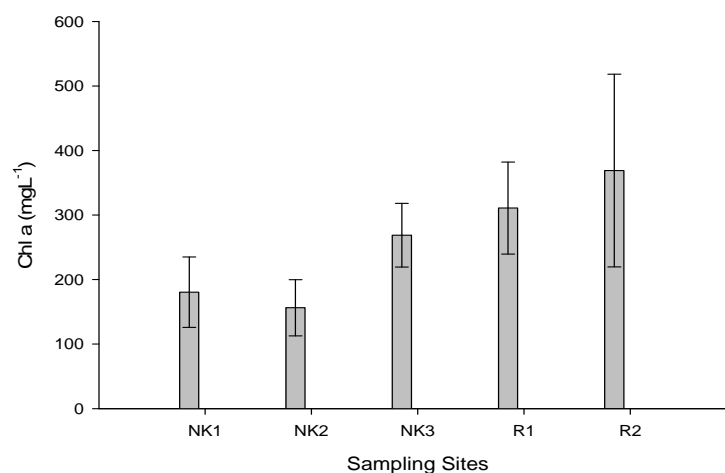
There were significant differences in fecal coliform counts between the five sampling sites of Nyakomisaro – Riana River ( $F_{4, 269} = 13.11$ ;  $p = 0.000$ ). Fecal coliform counts in sampling site NK1 were not significantly different from those of sampling site NK2 but NK1 had significantly lesser fecal coliform counts by between 513 – 1765 cells100ml<sup>-1</sup> than NK3, between 749 – 2000 cells100ml<sup>-1</sup> than R1 and between 310 – 1561 cells100ml<sup>-1</sup> than R2. Site NK2 was significantly lower by between 253 – 1505 cells100ml<sup>-1</sup> than that of NK3, between 489 – 1740 cells100ml<sup>-1</sup> than that of R1 and between 50 - 1301 cells100ml<sup>-1</sup> than that R2. Sampling site NK3 compared with other lower sites (R1 and R2) showed no difference in fecal coliform counts and site R1 was not significantly different from that of site R2 (figure 7).

The fecal coliform counts showed high significant differences in the five sampling sites of Nyakomisaro – Riana River ( $F_{4, 269} = 26.15$ ;  $P = 0.000$ ). Fecal coliform counts in sampling site NK1 were not significantly different from those of sampling site NK2 but were significantly lesser by between 619 – 1838 cells100ml<sup>-1</sup> than NK3, between 1106 – 2325 cells100ml<sup>-1</sup>

than R1 and between 941 – 2160 cells100ml<sup>-1</sup> than R2. Site NK2 was significantly lower by between 496 – 1715 cells100ml<sup>-1</sup> than that of NK3, between 983 – 2202 cells100ml<sup>-1</sup> than that of R1 and between 818 - 2037 cells100ml<sup>-1</sup> than that R2. Sampling site NK3 compared with other lower sites (R1 and R2) showed no difference in total coliform counts and site R1 was not significantly different from that of site R2 (figure 7).

### 3.7 Chlorophyll- a in Nyakomisaro – Riana River

The range of chlorophyll a in all the sampling sites of Nyakomisaro-Riana River was 0.00 – 4839.00 $\mu\text{g L}^{-1}$  and the overall mean of 257.13 $\pm$ 48.88 $\mu\text{g L}^{-1}$  (table 6). Sampling site NK2 had the lowest average Chl-a concentration of 156 $\pm$ 43.44 $\mu\text{g L}^{-1}$  while site R2 had the highest Chl a concentration of 368.98 $\pm$ 149.32  $\mu\text{g L}^{-1}$ . Though, site differences, there was no significant difference in algal concentrations among the five sampling sites ( $F_{4, 269} = 1.14$ ;  $p = 0.339$ ) indicating the eutrophic status of Nyakomisaro-Riana River (figure 8).

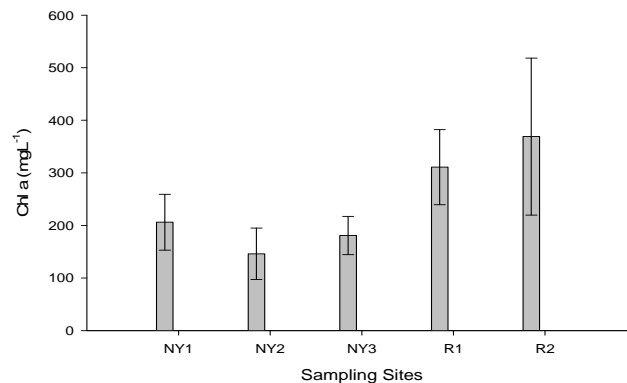
**Fig 8:** Mean Chlorophyll a concentration along the Nyakomisaro – Riana River during the May 2013 to October 2014 sampling period



### 3.8 Chlorophyll a in the Nyanchwa – Riana River

The range of chlorophyll a in all the sampling sites of Nyanchwa-Riana River was 0.00 – 4839.00 $\mu\text{gL}^{-1}$  and the overall mean of 242.66 $\pm$ 59.97 $\mu\text{gL}^{-1}$  (table 5). Sampling site NY2 had the lowest average Chl a concentration of 146.23 $\pm$ 48.98 $\mu\text{gL}^{-1}$  while site R2 had the highest Chl a

concentration of 368.98 $\pm$ 149.32  $\mu\text{gL}^{-1}$ . Though, site differences, there was no significant difference in algal concentrations among the five sampling sites ( $F_{4, 269} = 1.29$ ;  $p = 0.273$ ) (figure 9). This indicated that the Nyanchwa-Riana River is eutrophic at all sampling points.



**Fig 9:** Mean Chlorophyll a concentration along the Nyanchwa – Riana River during the May 2013 to October 2014 sampling period

### 4. Discussions

In both streams, TDS were within the range classified fair by world Health Organization [20]. Generally, TDS in Nyanchwa-Riana River with an overall mean TDS (142.59 $\pm$ 22.68 mgL<sup>-1</sup>) was higher than the overall mean TDS at Nyakomisaro-Riana River (96.62 $\pm$ 11.76 mgL<sup>-1</sup>). Similarly, the difference in Electrical conductivity in the Nyanchwa-Riana River was 110.35 $\pm$ 2.09  $\mu\text{Scm}^{-1}$  and at Nyakomisaro was (107.55 $\pm$ 4.15  $\mu\text{Scm}^{-1}$ ). The above recommended levels in TDS and EC of the two river profiles can be attributed to the washing of clothes, cars, sewage leakage, oils from nearby garages and organic waste which are often dumped voluntarily and non-voluntarily into these river profiles from the town and surrounding community. The comparable differences in both TDS and EC of the two river profiles can be attributed to the more cars which are washed at the Nyanchwa bridge, more leaked sewage since the sewer line runs parallel the Nyanchwa-Riana stream profile and the oils from the many garages along the river profile.

Total Dissolved Solids (TDS) are the total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water. TDS is directly related to electrical conductivity of water as;  $\text{TDS (mg/L)} = \text{EC } (\mu\text{S/cm at } 25^\circ\text{C}) \times 0.6$ . TDS levels in both the Nyanchwa – Riana and Nyakomisaro – Riana River water samples ranged between 2.00 – 1420.00 mgL<sup>-1</sup> and 2.00 – 781.00 mgL<sup>-1</sup> respectively. Therefore, the waters of these river profiles is considered fresh because as a rough estimation, freshwater may be considered to have TDS of 1500 mgL<sup>-1</sup> and the recommended maximum value for surface water bodies is 2000 mgL<sup>-1</sup> [21]. The high TDs is water can affect aquatic animals [22].

The total suspended solids (TSS) include the inorganic fraction (silts, clays, etc) and an organic fraction (zooplankton, bacteria, algae, and detritus) that are carried along by water as it runs off the land and these contribute to the murkiness of a water body [23]. Suspended solids can clog fish gills, and impairing their visibility resulting in either fish death, reduction in growth rate and inability to evade the predator. They also reduce light penetration, thereby reducing the ability of algae to produce food and oxygen as supported by studies and findings of Kentucky Water Watch (2001) [23]. Not always are TSS a bad attribute of water quality, they have a positive

effect of adsorbing toxic chemicals such as pesticides and metals and become complexes with them thereby making the toxics less available for absorption by both aquatic and terrestrial living organisms.

The TSS levels in the Nyanchwa – Riana and Nyakomisaro – Riana River profiles were both between and 2.00 – 396.00 mgL<sup>-1</sup>. The obtained high levels of TSS may have resulted due to re-suspension of silt from dumped construction sites soils [24], coarse and fine organic particulate matter from the organic wastes and leaked sewage materials along these river profiles. The upper TSS ranges were above the recommended NEMA levels of 30 mgL<sup>-1</sup> [25, 26].

The total and fecal coliform counts (T-coli) in the Nyanchwa – Riana water body along the sampling points ranged between 0.00 and 4300 (cells/ml). However, at site NY3, both T-Coli and F-Coli were highest with 740 $\pm$ 94 cells100ml<sup>-1</sup> and 627  $\pm$ 112 cells100ml<sup>-1</sup> respectively (fig 6), indicating a point source of contamination which invariably is the occasional leaking sewer line compounded with the human defecations on nearby bushes and the in-stream watering of animals. These high levels of F-coli pose continuing danger to human health [8]. Similarly, the total and fecal coliform counts in the sampling sites of Nyakomisaro-Riana River showed an incremental trend from the source to the lower reaches. Generally, there was a monotonic increase of total and fecal coliform counts down the river (figure 7) indicating human and animal interference. The range of both Fecal and Total coliform counts were 0 - 4500 cells100ml<sup>-1</sup> and the overall means of F-coli and T-coli were 786 $\pm$ 104 cells100ml<sup>-1</sup> and 842 $\pm$ 105 cells100ml<sup>-1</sup> respectively (table 6). The high fecal coliform counts at R1 can be attributed to the sewage leakage which spills into the river, stream bathing [27], dumped animal waste [28] from Mwembe estate, direct watering of animals at various points of this river and the toilet spill over all of which are along the riparian zone of this river. At sampling site R2, the high fecal coliform counts can be due to the Suneka Lagoon sewage release into the Riana River which is not well treated to lessen the fecal coliform counts [29]. The results compared with the NEMA standards, confirm that the water quality can be good for bathing, irrigation but not for drinking [25, 26].

Chlorophyll-a is the most common photosynthetic pigment found in all plants, algae, and cyanobacteria. Its concentration

provides a good assessment of the primary production or algal activities in a waterbody. The direct causes of algal blooms are often associated with increased total phosphorous (TP) and/or total nitrogen (TN) levels in a waterbody<sup>[30]</sup>. Both rivers had chlorophyll-a concentrations (tables 5&6) which were far above the threshold number of classifying the waters to be of poor taste and full of odor in both rivers. Taste and odor problems begin to occur once chlorophyll-a values reach 10  $\mu\text{gL}^{-1}$ <sup>[31]</sup>. There were no significant differences in chlorophyll a concentrations among the sampling sites of both rivers an indication that these two streams are eutrophic. High chlorophyll concentrations are the most obvious symptom of classic eutrophication, and it frequently leads to other problems. Chlorophyll *a* is a core parameter for the measurement of water quality<sup>[32]</sup> and a requirement for compliance in water quality measurements<sup>[33]</sup>.

## 5. Conclusions

The water from both rivers is not of good quality for consumption purposes, therefore the Gusii Water and Sanitation Company (GWASCO) has to develop policies on water quality and sensitize the people in order to avoid the pollutants entering these rivers. If the inhabitants of Kisii town have to use the water from these two rivers, they must treat and control the car washing, sewerage leakage and defecations on nearby bushes.

## 6. Acknowledgements

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